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# THE FLUID SYSTEMS FOR THE SLD CHERENKOV RING IMAGING DETECTOR\*

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## Abstract

We describe the design and operation of the fluid delivery, monitor and control systems for the SLD barrel Cherenkov Ring Imaging Detector (CRID). The systems deliver drift gas (C<sub>2</sub>H<sub>6</sub>+TMAE), radiator gas (C<sub>8</sub>F<sub>12</sub>+N<sub>2</sub>) and radiator liquid (C<sub>8</sub>F<sub>14</sub>). Measured critical quantities such as electron lifetime in the drift gas and ultra-violet (UV) transparencies of the radiator fluids, together with the operational experience, are also reported.

## 1 Introduction

The SLD barrel CRID [1], which was partially commissioned in 1991 [2, 3], is now fully operational [4, 5]. A combination of gaseous (a mixture of 30% N<sub>2</sub> and 70% C<sub>8</sub>F<sub>12</sub>, n=1.0013 at λ=1900Å) and liquid (C<sub>8</sub>F<sub>14</sub>, n=1.277 at λ=1900Å) radiators allows π/K/p separation up to 30 GeV/c. 40 quartz-windowed time projection chambers (TPCs) are employed as photon detectors. The base drift gas (C<sub>2</sub>H<sub>6</sub>) is doped with tetrakis (dimethylamino) ethylene (TMAE), which has a low ionization potential of 5.4 eV [6] and serves as the photo-cathode. The CRID vessel is filled with the radiator gas. The thickness of the gas

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radiator is 45 cm at  $\theta=90^\circ$ . The Cherenkov photons are reflected by spherical mirrors and focused onto the TPCs. The CRID has 40 quartz-windowed 1 cm-thick liquid radiator trays. The Cherenkov photons from the trays are proximity focused onto the TPCs.

Because the system is large, fragile, and susceptible to contaminations, the stability of operation and the maintenance of high quality fluids over an extended running period are major concerns.

Since each Cherenkov photon yields only one photoelectron and the photo-electrons drift up to 127 cm along the TPCs, it is essential to keep a long electron lifetime in the drift gas. Also, high UV transparencies of the radiator fluids must be maintained, because only about 10 photo-electrons are expected in each ring. Furthermore, since the radiator fluids are expensive, they must be re-circulated.

To ensure that the fluids are of good quality, the fluid systems are equipped with on-line monitoring systems. The systems continuously measure electron lifetime in the TPC gas, UV transparencies of all fluids, and oxygen and water vapor concentrations in the base drift gas and the radiator gas.

Each fluid pressure is carefully maintained within a few Torr of atmospheric pressure to protect the fragile and expensive internal components. The drift gas and radiator gas systems use mass flow controllers and a custom safety valve controller, while the liquid radiator system is an "intrinsically safe" gravity-feed system.

The vessel is heated to 30°C, because the TMAE vapor and the radiator gas mixture condense at room temperature. An uninterruptible power source and a fail-proof control system are required to avoid accidental condensation. Condensed TMAE in the manifolds or in the TPCs would react with impurities remaining on the surface and reduce the electron lifetime significantly. Condensation of  $C_2F_{12}$  would leave spots on the optics and could cause severe under-pressure in the vessel.

## 2 Fluid Monitoring and Control Systems

A detailed description of the monitoring and control systems can be found elsewhere [7]. The systems are described briefly here.

A dedicated stand-alone computer (VaxStation II) is used for monitoring and control. The various quantities monitored are stored in a database as time histories.

The UV transparencies of all fluids are measured by two on-line UV monitoring systems. One of them is used for gases and the other for liquids. The radiator gas can be measured in both the gas and the liquid phases. The UV monitoring systems contain a deuterium lamp with a  $MgF_2$  window<sup>1</sup>, a monochromator<sup>2</sup> and photomultipliers with wavelength shifters. The ratio of the light intensity through the sample fluids to that through clean nitrogen, which is UV transparent, gives the UV transparency.

<sup>1</sup>1.879-01: Hamamatsu Photonics, Hamamatsu 430, Japan.

<sup>2</sup>77250 Monochromator: Oriel Co., Stratford, CT 06497, USA.

The electron lifetime monitor (ELM) [8] is a miniature ionization chamber containing an  $^{241}\text{Am}$  source. The ELM measures the pulse-height spectrum of drift electrons from the source with various drift fields in the chamber. The relation between the pulse-height and the drift field (i.e. drift time) yields the electron lifetime.

Oxygen and water vapor levels are measured by commercial equipment<sup>3,4</sup>. Both measure concentration down to the 1 ppm level. However, the oxygen sensor is not compatible with TMAE-laden gas, therefore, measurements must be done before TMAE is added.

The vessel and the components are heated by approximately 200 heaters. Half of them are backed up by a diesel generator in the event of a power failure. The temperature of the vessel is monitored by approximately one thousand temperature sensors<sup>5</sup>. The control system is CAMAC-based with hardware back-up. The back-up control system utilizes a small number of platinum temperature sensors<sup>6</sup>. This back-up system takes over control if the activity in the CAMAC crate is interrupted for more than 5 minutes.

The power source for the temperature control system and the flow/pressure control system for the TPC gas and the radiator gas is backed up by a diesel generator. It is also backed up by batteries to avoid transients on switching from the commercial power to the diesel generator.

## 3 Fluid Delivery Systems

The fluid delivery systems have been made under strict quality control. Compatibility of all materials with the fluids has been tested to eliminate possible contamination and/or degradation of the fluids. Electro-polished stainless steel tubing has been used in all fluid sub-systems. The systems must be exceptionally leak tight. This is particularly true in the TMAE-laden drift gas system.

### 3.1 Drift Gas Delivery System

The drift gas delivery system is shown schematically in Fig. 1. The base drift gas ( $C_2H_6$ ) is filtered to remove impurities and delivered through a mass flow controller (MFC)<sup>7</sup>. The gas is then bubbled through liquid TMAE using a constant temperature bubbler to pick up a small amount of TMAE vapor, and then sent to the TPCs. The nominal flow rate is 7ℓ/min. for all 40 TPCs. Each TPC has a capacity of approximately 37ℓ. The pressure on the TPCs, which is kept about one Torr higher than the vessel pressure, is defined by the flow rate and the oil levels in the bubblers on the exhaust manifolds. The pressure is monitored by a pair of capacitance manometers<sup>8</sup>. Two shut-off

<sup>3</sup>Trace Oxygen Analyzer: Teledyne Analytical Instruments, City of Industry, CA 91749, USA.

<sup>4</sup>System 6 Hygrometer: Panametrics Inc., Waltham, MA 02254, USA.

<sup>5</sup>AD-590: Analog Devices, Norwood, MA 02062, USA.

<sup>6</sup>F3101: Omega Engineering Inc., Stamford, CT 06907, USA.

<sup>7</sup>Model 1258A: MKS Inc., Burlington, MA 01803, USA.

<sup>8</sup>Model 221AD: MKS Inc., Burlington, MA 01803, USA.

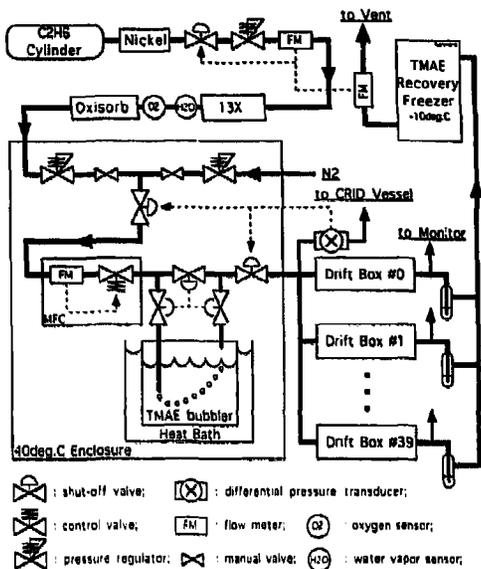


Figure 1: Drift gas delivery system.

valves and the MFC stop the flow when the box pressure strays from the operating range. The TMAE in the exhaust gas is recovered in a refrigerator which is cooled to about  $-10^{\circ}\text{C}$ .

Since TMAE is extremely reactive, in particular with oxygen, and because some of the reaction products are highly electronegative, very pure base drift gas and an extremely leak-tight system are required. To achieve the desired purity (less than 1 ppm of oxygen), high purity ethane gas<sup>9</sup> is filtered by molecular sieve (13X) and Oxisorb<sup>10</sup>. The oxygen readings in the TPC exhaust gases are typically less than 1 ppm (Fig. 2a). The oxygen meter has an offset of about 0.6–0.7 ppm, therefore the oxygen levels in most of the TPCs are nearly zero. A few ppm of elemental sulfur, which could react with some of the TPC materials, has been found in the supply gas. The amount of sulfur present in the gas is batch dependent. To eliminate this sulfur, a nickel-catalyst filter<sup>11</sup> is placed right after the ethane cylinder. However, the filter seems to outgas oxygen when it is heated either during activation or exothermally as it absorbs sulfur. Therefore, another Oxisorb filter has been added after the nickel-catalyst filter (not shown in the figure) to ensure that the oxygen level at the final Oxisorb filter remains low.

As delivered by the vendor, TMAE<sup>12</sup> contains a number of contaminants. Our TMAE purification procedure is the

<sup>9</sup>Alpha Gas Co., Walnut Creek, CA 29596, USA.

<sup>10</sup>Messer Greeshiem GmbH, D-4000 Düsseldorf 30, Germany.

<sup>11</sup>N1-0104-T-1/8: Engelhard Co., Iselin, NJ 08830, USA.

<sup>12</sup>Source: RSA Co., Ardsley, NY 10502, USA.

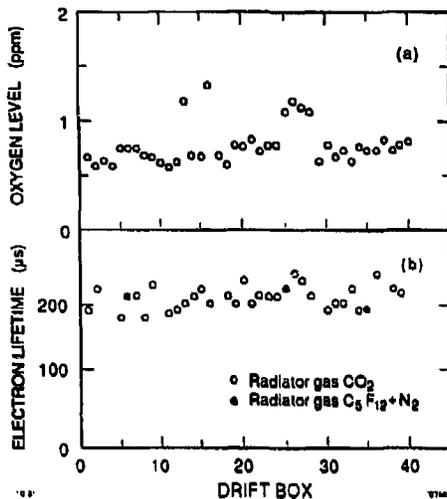


Figure 2: Oxygen levels and electron lifetimes in the TPCs. The oxygen sensor has an offset of 0.6–0.7 ppm. The electron lifetimes were measured with  $\text{CO}_2$  (open circles) or  $\text{C}_5\text{F}_{12}+\text{N}_2$  (solid circles) in the vessel.

following:

1. Water washing: TMAE is mixed and shaken with de-oxygenated HPLC-grade water<sup>13</sup> so that contaminants are dissolved in the water. Because TMAE is lighter than water, the TMAE floats to the top of the water. The water is then discarded from the bottom of the container. This process is repeated three times.
2. Filtering: The TMAE is dried and filtered through silica gel and molecular sieve (3Å and 4Å). This step shortens the time required for the next step considerably.
3. Pumping: The TMAE is pumped at low pressure (20–80 Torr) for 4–12 hours with a small flow of methane gas bubbling through it until good electron lifetime is obtained.

By this procedure, enough TMAE for two years of operation has been purified.

The TMAE bubbler temperature is maintained at  $23.5^{\circ}\text{C}$ , which corresponds to a concentration of 0.06% and an absorption length of 19 mm at  $\lambda=1700\text{--}1950\text{Å}$  [9, 10]. Fig. 2b shows the electron lifetimes in the TPC exhaust gases measured in the ELM. The electron lifetimes are about  $200\mu\text{s}$  and do not degrade even when highly electronegative  $\text{C}_5\text{F}_{12}$  is introduced into the radiator vessel<sup>14</sup>.

<sup>13</sup>J.T. Baker Inc., Phillipsburg, NJ 08965, USA.

<sup>14</sup>Note: The electron lifetime measured in the ELM may not be equal to that in the TPCs, because the drift fields are different.

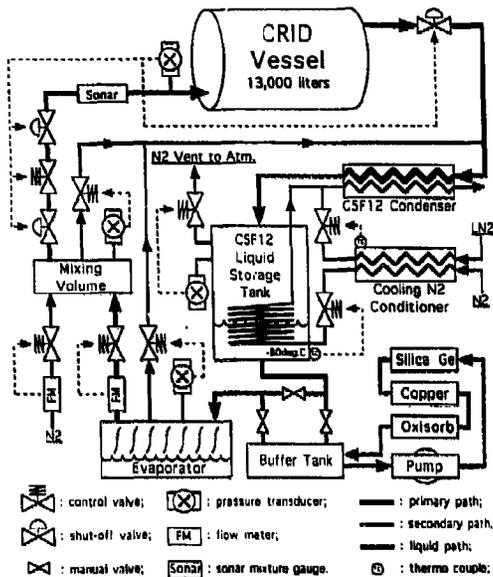


Figure 3: Gas radiator ( $C_5F_{12}$ ) circulation system.

### 3.2 Gas Radiator Circulation System

The radiator gas is a mixture of  $C_5F_{12}$  (70%) and nitrogen (30%), because the boiling point of  $C_5F_{12}$  ( $28^\circ C$ ) is close to the vessel operating temperature ( $30^\circ C$ ). The condensation point of this mixture is about  $20^\circ C$ .

Fig. 3 shows the circulation system of the radiator gas. Liquid  $C_5F_{12}$ <sup>15</sup> is stored in a tank which is cooled to around  $-80^\circ C$ . The liquid is boiled in an evaporator and acquires enough pressure to be sent to the vessel. This evaporated gas is then mixed with purified nitrogen and sent to the radiator vessel.  $C_5F_{12}$  in the return gas is condensed in a heat exchanger and stored in the storage tank. The nitrogen, still in the gas phase, is released from the storage tank. The flow rate is typically 30–40ℓ/min. and the vessel capacity is 13,000ℓ.

The sound velocity in the vessel is measured to check stability and uniformity of the mixture [11]. Sonar transmitters and receivers are located at three levels on the vessel. A 0.1% fluctuation of the mixture is detectable with this system. The measured uniformity and the stability in the vessel are about  $\pm 1\%$ .

The head space of the storage tank is purged with nitrogen gas, which carries away any impurities remaining in the gas phase at the tank temperature (such as oxygen). The liquid  $C_5F_{12}$  is cleaned by silica gel, activated copper<sup>16</sup>, and an Oxisorb filter in a closed loop circulation system during normal operation and also prior to loading

<sup>15</sup> PF-5050: 3M Co., St. Paul, MN 55144, USA.

<sup>16</sup> Engelhard Co., Elyria, OH 44035, USA.

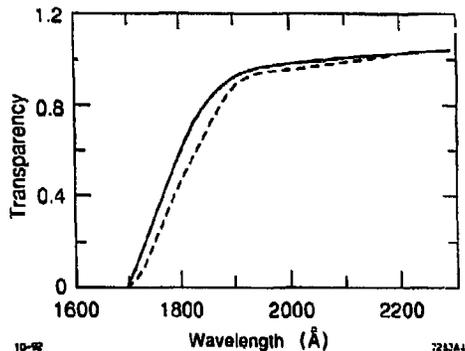


Figure 4: Transparencies of 1 cm of clean  $C_5F_{12}$  liquid (solid), and liquid circulated for 11 days without filtration (dashed).

into the system.

Fig. 4 shows the UV transparency of 1 cm of liquid, which is equivalent to 120 cm in the gas phase. The transparency reduces when the gas is circulated without filtration. The oxygen and water vapor levels in the return gas are typically about 5 ppm and 50 ppm respectively, and not large enough to explain this degradation. However, after passing through the filtration system, the transparency is recovered in full.

### 3.3 Liquid Radiator Circulation System

Fig. 5 shows the liquid radiator circulation system. The system uses only gravity to move the fluid through the liquid trays.  $C_5F_{14}$  liquid<sup>17</sup>, stored in a reservoir tank, is pumped by two gear pumps<sup>18</sup> and sent to two distribution tanks which are located above the CRID vessel. About one half of the liquid is filtered through an Oxisorb filter. Then the liquid is sent to spill tanks (overflow devices) which feed the liquid trays by gravity. Most of the spill tanks service only one tray. The pressure heads in the liquid trays are defined and limited by the liquid levels in the spill tanks. The liquid from the trays and the spill tanks is drained into a sump at the bottom of the SLD detector. The liquid is then pumped back up to the reservoir tank.

The entire system is in contact with a purified nitrogen buffer gas which serves as a pressure reference. The buffer gas communicates with the atmosphere through a bubbler and a  $C_5F_{14}$  condenser which traps  $C_5F_{14}$  vapor from the reservoir tank. A safety bubbler on the sump protects the quartz windows on the liquid trays from overpressure.

To confirm that the liquid trays are full, a level sensor which employs a device containing an infrared LED and

<sup>17</sup> PF-5060: 3M Co., St. Paul, MN 55144, USA.

<sup>18</sup> Micropump, Concord, CA 94524, USA.

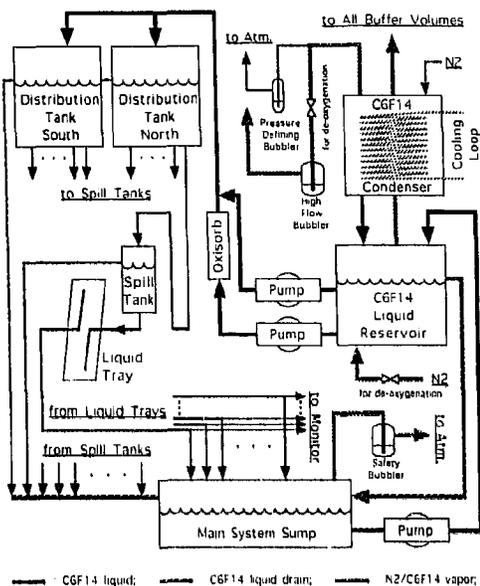


Figure 5: Liquid radiator ( $C_6F_{14}$ ) circulation system.

a photo-transistor<sup>19</sup> has been developed. This device is normally used to measure the reflectivity of surfaces in front of it. With a drop of epoxy (Epon 826<sup>20</sup> or Versamid 140<sup>21</sup>) on its face, it reflects less light on its surface when it is immersed in  $C_6F_{14}$  liquid.

$C_6F_{14}$  liquid is cleaned by the following procedure. Clean boil-off nitrogen is initially bubbled at a high flow rate through the liquid in the reservoir in order to de-oxygenate the liquid. This process reduces the oxygen concentration of 250ℓ of liquid, which is initially contaminated with 135,000 ppm of oxygen, down to ~20 ppm in about 24 hours. At this point, the nitrogen bubbling is stopped and normal circulation through an Oxisorb filter is established.

Fig. 6 shows the UV transparencies of 1 cm of liquid under various conditions. Clean de-oxygenated liquid, fully oxygenated liquid, together with liquids exposed to G10 for 107 days, and to epoxy (DP-190)<sup>22</sup> for 128 days are shown. G10 and DP-190 are used in the construction of the trays. Oxygen cuts off the transparency at shorter wavelengths, while the contamination from G10 cuts off at longer wavelengths. The contamination from DP-190 reduces the transparency drastically. However, the UV transparency can be restored by the cleaning system. Also, the rate of contamination is expected to decrease substantially as the trays "age".

<sup>19</sup>SFH600-2: Siemens AG, D-8000 München 80, Germany.

<sup>20</sup>Shell Chemical Co., Houston, TX 77019, USA.

<sup>21</sup>Henkel Co., Gulph Mills, PA 19406, USA.

<sup>22</sup>3M Co., St. Paul, MN 55144, USA

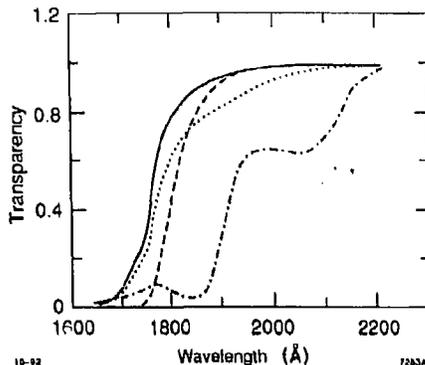


Figure 6: Transparencies of 1 cm of clean  $C_6F_{14}$  liquid (solid), fully oxygenated liquid (dashed), liquid exposed to G10 for 107 days (dotted), and liquid exposed to DP-190 for 128 days (dot-dashed).

## 4 Summary

The fluid systems have been operating since the summer of 1991 without any serious problems. We are maintaining good UV transparencies and long electron lifetime. However, the systems still require extensive routine care. A number of improvements must be made, in particular, in the monitoring and control systems, for years of stable operation.

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